

PHD PROJECT DESCRIPTION

(4000 characters max., including the aims and work plan to be published online)

Project title: A 'greener way' to obtain 2D and 3D nano- and microstructures from the gas phase

1.1. Project goals

- development of finding 'greener' new precursors matched to specific vapor deposition techniques,
- synthesis using mechanochemistry and limited solvent methods,
- studies of reactions in the gas phase and solid state,
- understanding mechanisms of electron/ion and laser beam interactions with adsorbed molecules,
- selection of promising precursors,
- obtaining micro- and nanomaterials with defined properties,
- applications of materials in 'green and sustainable ' nanotechnology

1.2. Outline

Micro- and nanomaterials containing transition metals are used in electronics, optoelectronics, plasmonics, catalysis, and antimicrobial agents. They can be obtained by gas-assisted methods such as chemical vapor deposition (CVD), where one or more volatile precursors are transported to the reactor and decompose on a heated substrate. Nowadays, the advanced process, so-called 3D nano-printing, such as e.g., focused electron beam induced deposition (FEBID) or focused ion beam induced deposition (FIBID), allows obtaining deposits of a unique composition or shape. Therefore, volatile metal complexes, which consist of an 'ink', play a crucial role in the success during the deposition, and they influence the development of nanotechnology. Currently, the synthesis of precursors is carried out using classical methods with significant solvent consumption. In addition, volatility-enhancing substituents mostly contain fluorinated groups (PFAS), which should be limited from use in line with global trends. Therefore, it is necessary to look for complexes with reduced content of this element. However, they should still be able to generate volatile metal carriers at low temperatures, which properly decompose, forming the desirable material. New 'greener' and user-friendly precursors, which can be used in the one-step fabrication of materials, are still sought.

1.3. Work plan

- Classic and 'green' synthesis of new potential precursors,
- Complexes' composition and structure studies,
- Determination of volatility and thermal stability of the compounds,
- The use of calculations (also AI) to find or confirm the relation between molecules'

structure and physicochemical properties,

- Studies of molecule sensitivity to electrons or ions, a laser beam, etc..
- Propose mechanisms of interactions for promising precursors,
- Fabrication of nano- and micromaterials for 'green' applications
- Morphology, composition, and properties characteristics of the obtained materials,
- Studies of the activity of promising selected materials, particularly in the field of photocatalysis and sensing.

1.4. Literature (max. 7 listed as a suggestion for a PhD candidate preliminary study)

- 1) I. Utke, P. Swiderek, K. Höflich, K. Madajska, J. Jurczyk, P. Martinović, I. B. Szymańska, Coord. Chem. Rev., 458 (2022) 213851.
- 2) S. Barth, M. Huth, F. Jungwirth J. Mater. Chem. C 2020, 8, 15884-15919.
- 3) P. Martinović, M. Rohdenburg, A. Butrymowicz, S. Sarigül, P. Huth, R. Denecke, I. B. Szymańska, P. Swiderek, Nanomaterials, 12 (2022) 1687.
- 4) A Butrymowicz-Kubiak, A.Topolski, T.Muzioł, I.B. Szymańska, Dalton Trans., 54, (2025), 9651, DOI: 10.1039/d5dt00550g
- 5) L. Berger, K. Madajska, I. B. Szymańska, K. Höflich, M. N. Polyakov, J. Jurczyk, C. Guerra-Nuñez, I. Utke, Beil.stein J. Nanotechnol, 9 (2018) 224.
- 6) R. Córdoba, P. Orús, S. Strohauser, T. Torres, J. M. De Teresa, Scientific Reports, 9 (2019) 14076.
- 7) A.Butrymowicz-Kubiak,T. Muzioł,A. Kaczmarek-Kędziera, Ch.Jureddy , K.Maćkosz, I.Utke, I.B.Szymańska, Dalton Trans., 53 (2024), 13662, DOI:10.1039/d4dt01287a

1.5. Required initial knowledge and skills of the PhD candidate

- Analytical thinking
- Eager to learn
- Teamwork
- Experience in basic chemical synthesis and spectroscopy
- Understanding of nano- and micromaterials synthesis and analysis
- Basic knowledge of deposition techniques and 'green transition'
- Keen to learn new techniques, instrumentations, and calculations
- Thinking oriented on innovation and application

1.6. Expected development of the PhD candidate's knowledge and skills

- Improve analytical thinking,
- Understanding why we still need to learn,
- Organization of teamwork,
- High experience in advanced chemical synthesis,
- Extensive experience in spectroscopic data analysis,

- Fluency in materials synthesis and analysis,
- Advanced knowledge of nanomaterial's deposition techniques ,
- Knowledge of modern techniques and instrumentation, and the ability to do classic calculations and to use AI methods,
- Thinking highly focused on innovation, application, and the introduction of 'green chemistry and sustainable development' solutions to studies.